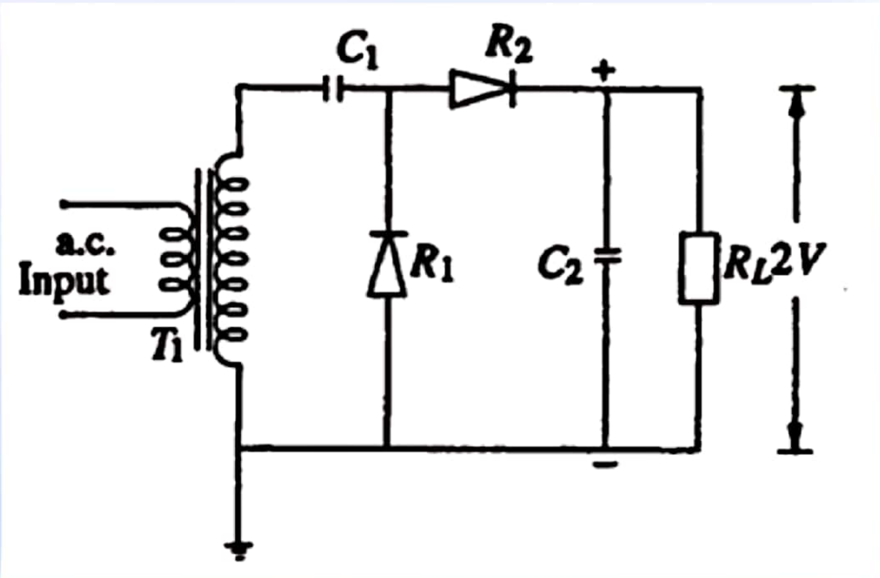
1.3 Voltage doubler



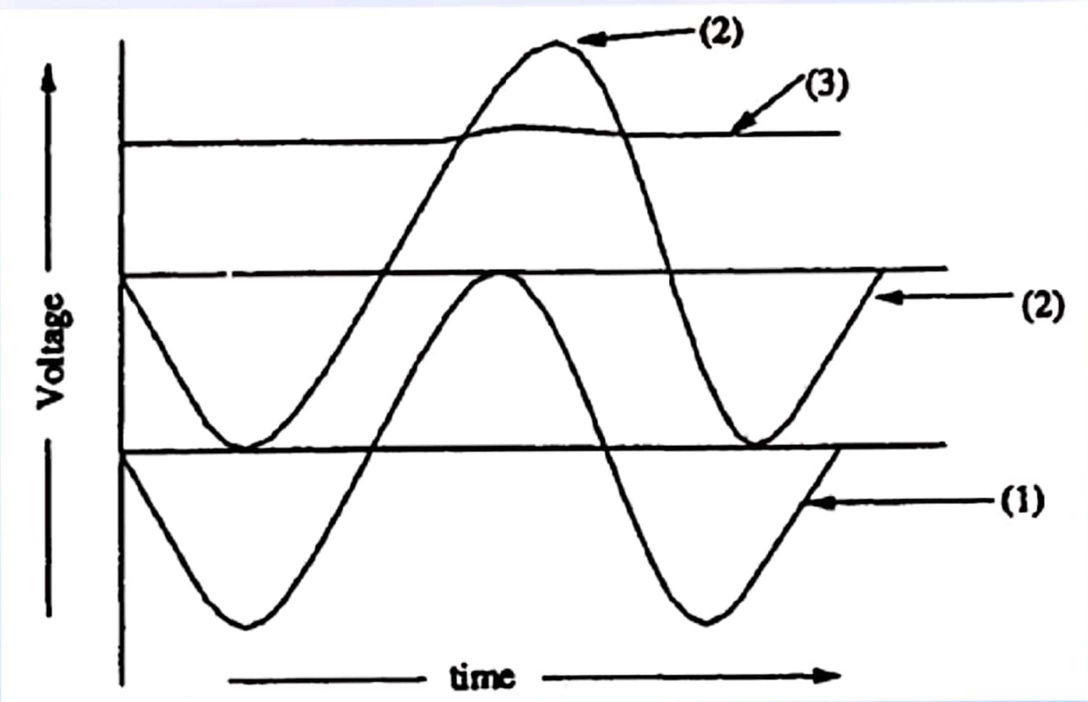
Negative half cycle :

1. Rectifier R_1 is forward biased and rectifier R_2 is reverse biased
2. Capacitor C_1 charges to V_{max} through rectifier R_1 with polarity shown

Positive half cycle :

1. Rectifier R_2 is forward biased and rectifier R_1 is reverse biased
2. Capacitor C_2 charges to 2 V_{max} through rectifier R_2

Voltage doubler waveforms:



(1) a.c. input voltage waveform

(2) a.c. output voltage waveform without condenser filter

(3) d.c. output voltage with condenser filter

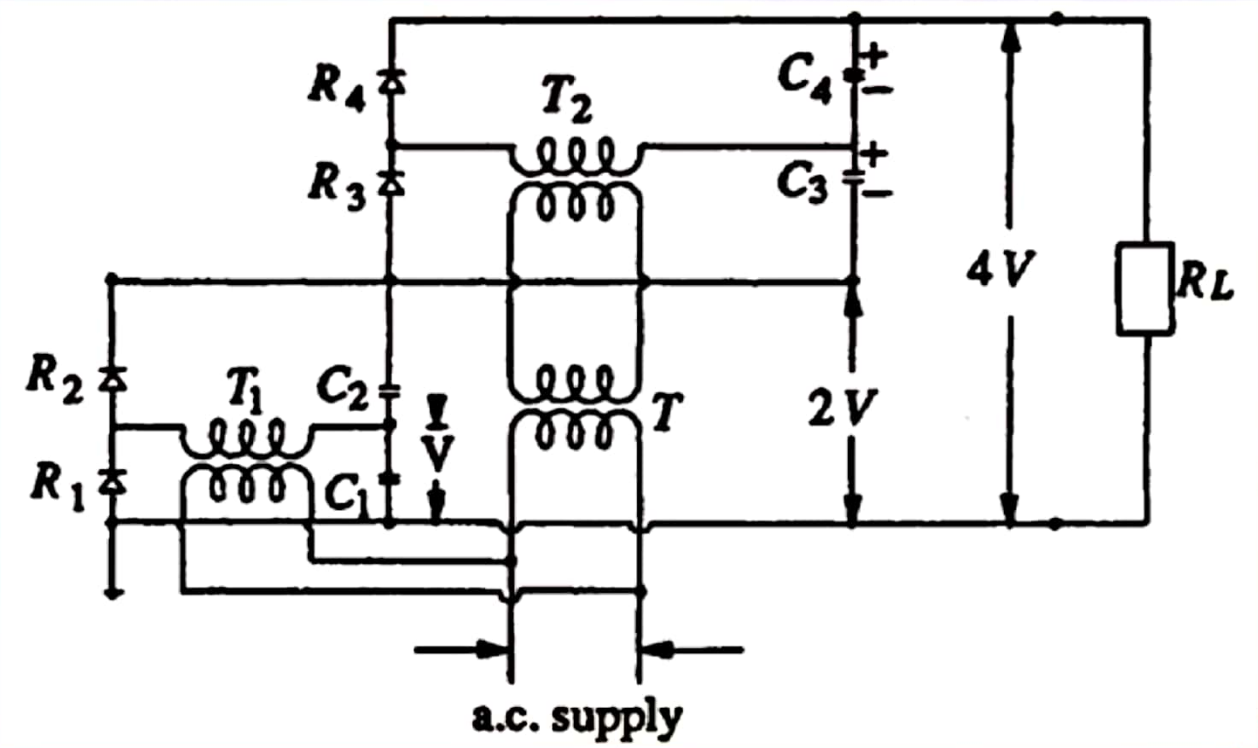
Circuit operation :

1. During negative half cycle the condenser C_1 gets charged through rectifier R_1 to a maximum voltage of $+V_{max}$ with polarity shown in diagram.
2. In the positive half cycle as the transformer voltage rises to V_{max}, the potential of other terminal of C_1 rises to $+2V_{max}$.
3. Thus, condenser C_2 charges through rectifier R_2 to a potential of $2V_{max}$.
4. The d.c. output voltage on load will be less than $2V_{max}$, depending on the time constant $C_2 R_L$ and the charging time constant.

Circuit operation :

5. The ripple voltage can be minimized to less than 2% if the following conditions are fulfilled: Ratio $R_L/r \leq 10$ and $X/r \leq 0.25$, where X and r are reactance and resistance of input transformer.
6. Peak inverse voltage rating of rectifiers is $2V_{max}$, and condensers C_1 and C_2 are also rated for same voltage.
7. The ripple voltage increases with increase in load current.
8. Cascaded voltage doublers are used when higher voltages are required without changing the input transformer voltage level.

1.4 Cascaded Voltage doubler:



Circuit operation :

1. The rectifiers R_1 and R_2 with transformer T_1 along with condensers C_1 and C_2 form simple voltage doubler providing output voltage of 2V as described above.
2. This circuit is duplicated and connected in series or cascade to obtain further voltage doubling to 4V.
3. Transformer T provides isolation to transformer T_2 as it is at maximum voltage of $2V_{max}$ above ground.
4. The values of all condensers must be equal in order to maintain uniform voltages across the rectifier string R_1 , R_2, R_3 and R_4.

Circuit operation:

5. The arrangement may be extended by adding more stages to obtain voltages 6V, 8V or higher.
6. The design of isolation transformer at higher voltage levels becomes cumbersome above voltage of 4V as cathode potential of higher stage rectifiers are at high potential above ground.

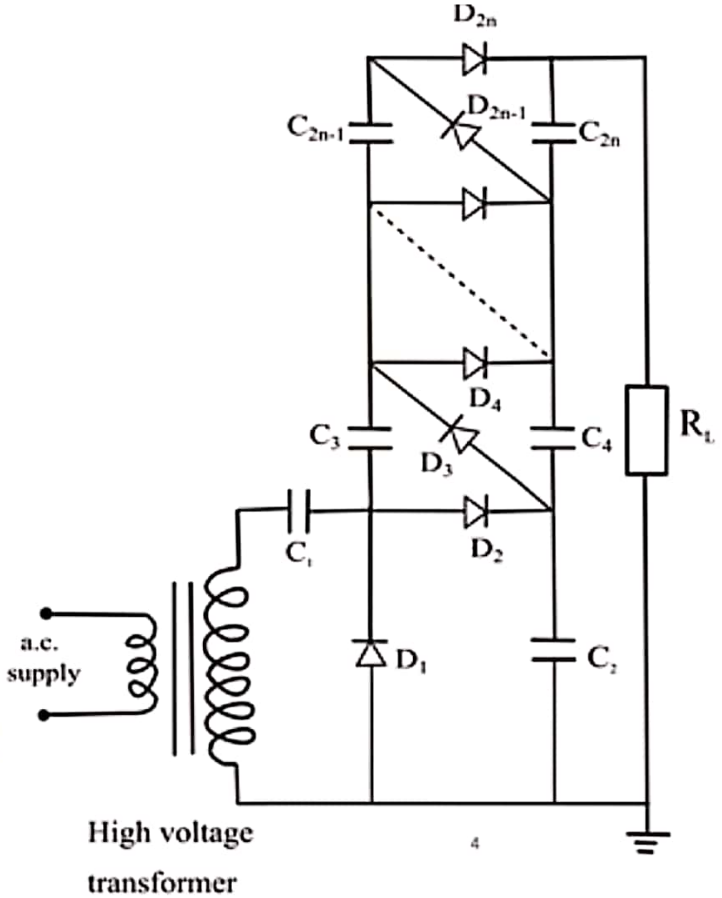
1.4 Cockroft- Walton voltage multiplier

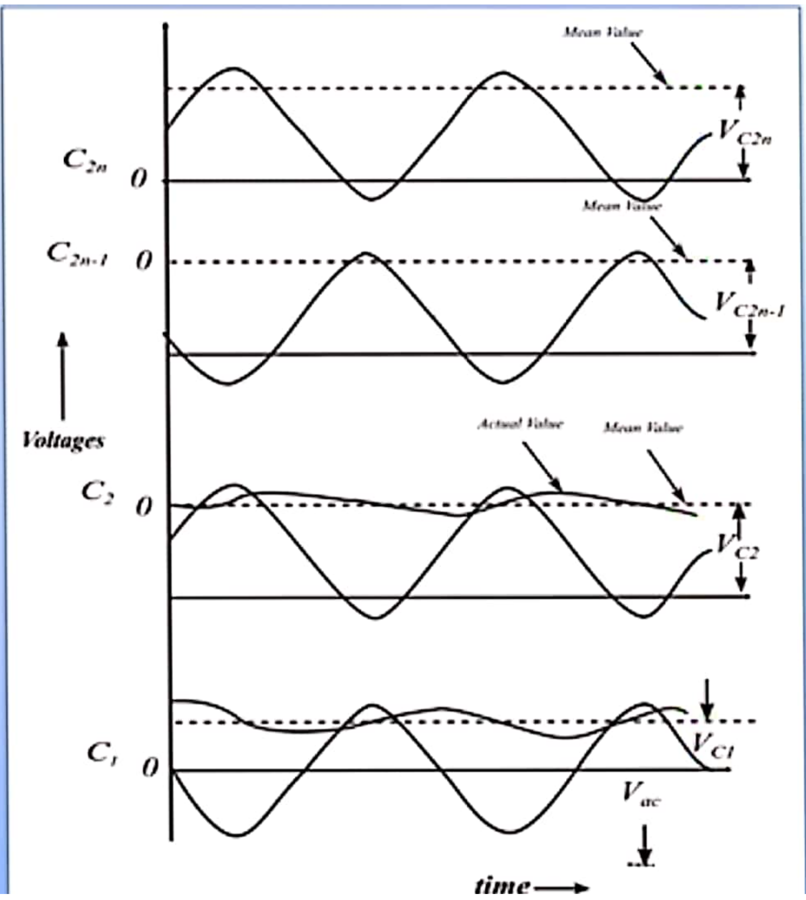
Voltage doubler operation :

1. Rectifier D_1 , D_2 , Capacitors C_1, C_2 and transformer T form voltage doubler circuit.
2. Higher voltages of 4, 6,..2n times the input voltage V can be obtained using 'n' stages connected in series.

Higher voltage operation:

1. Rectifiers D_1, D_3, ..D_{2n-1} conduct during negative half cycle.
2. Rectifiers D_2, D_4, ..D_{2n} conduct during positive half cycle.





Voltage multiplier waveforms:

- Voltage across capacitor C_2 is sum of supply voltage and voltage across capacitor C_1.
- The mean voltage V_{C2} is less than the peak positive value of sum of ($V_{ac} + V_{C1}$).
- The mean values of voltages across all capacitors C_2 …..C_{2n} can be derived in similar manner.

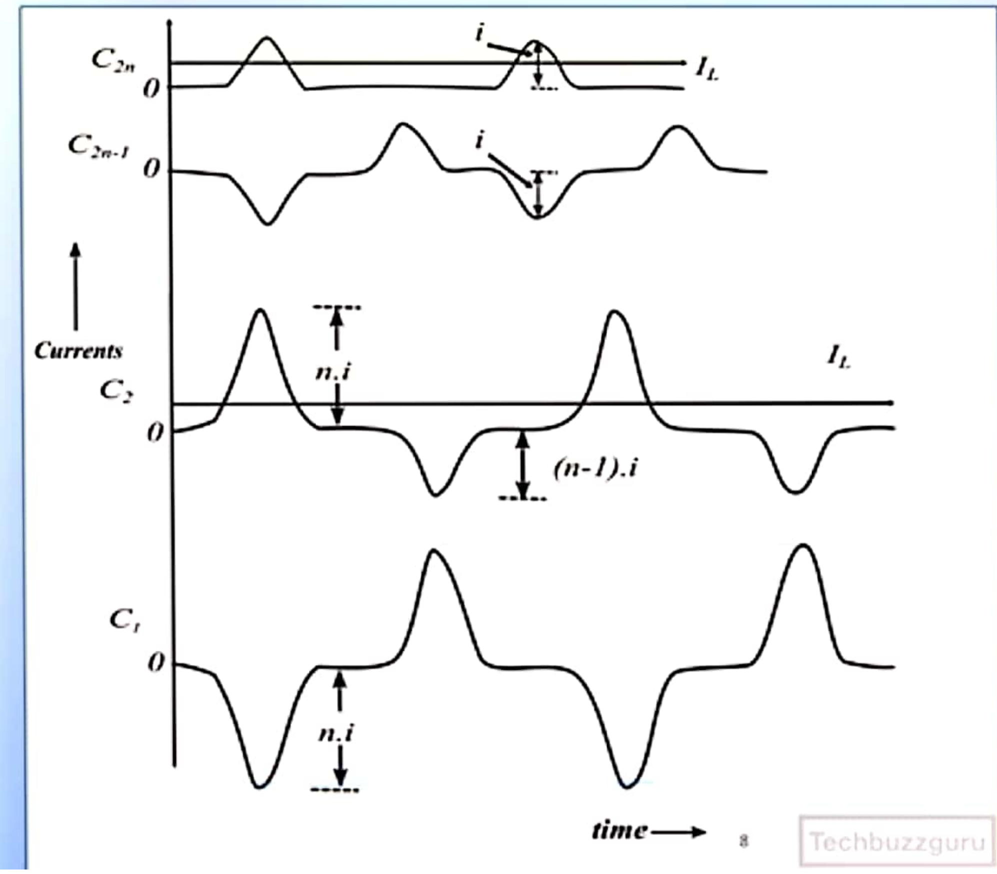
Circuit operation :

1. The first stage of Cockroft - Walton voltage multiplier consist of voltage doubler circuit formed by Rectifiers (D_1, D_2) , Capacitors (C_1, C_2) and transformer T.
2. A number of voltage doubler circuits are shown to be added in series or cascade to obtain higher voltages. If 'n' number of stages are added, then peak d.c. voltage developed will be '2n' times the peak secondary voltage of high voltage transformer.
3. The capacitor C_4 is charged to $4V_{max}$ and similarly capacitor C_{2n} will be charged to $2nV_{max}$ with respect to ground.
4. The individual capacitor in every stage will have potential of $2V_{max}$.

Circuit operation :

5. Rectifiers D_1, D_3, ..D_{2n-1} conduct during negative half cycle. Rectifiers D_2, D_4, ..D_{2n} conduct during positive half cycle.
6. Voltage across capacitor C_2 is sum of supply voltage and voltage across capacitor C_1.
7. The mean voltage V_{C2} is less than the peak positive value of sum of (V_{ac} + V_{C1}).
8. The mean values of voltages across all capacitors C_2 .....C_{2n} can be derived in similar manner.

Current waveforms:



Total ripple voltage equation :

$$\boxed{\delta V_{Total} = \frac{I_L}{fC} \cdot \frac{n(n+1)}{2}}$$

where, I_L = Load current from rectifier

f = supply frequency

C = equal value of capacitors in each stage

n = total number of stages

Voltage regulation or voltage drop :

$$\boxed{\Delta V = \frac{I_L}{fC} \cdot \left[\frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}\right]}$$

Optimum number of stages for minimum voltage drop :

$$\boxed{n_{optimum} = \sqrt{\frac{V_{max} fC}{I}}}$$

where, V_{max}= Peak rated transformer secondary voltage

Maximum possible output voltage :

$$[V_0]_{max} = n_{optimum} \times \frac{4}{3} \times V_{max}$$

Summary:

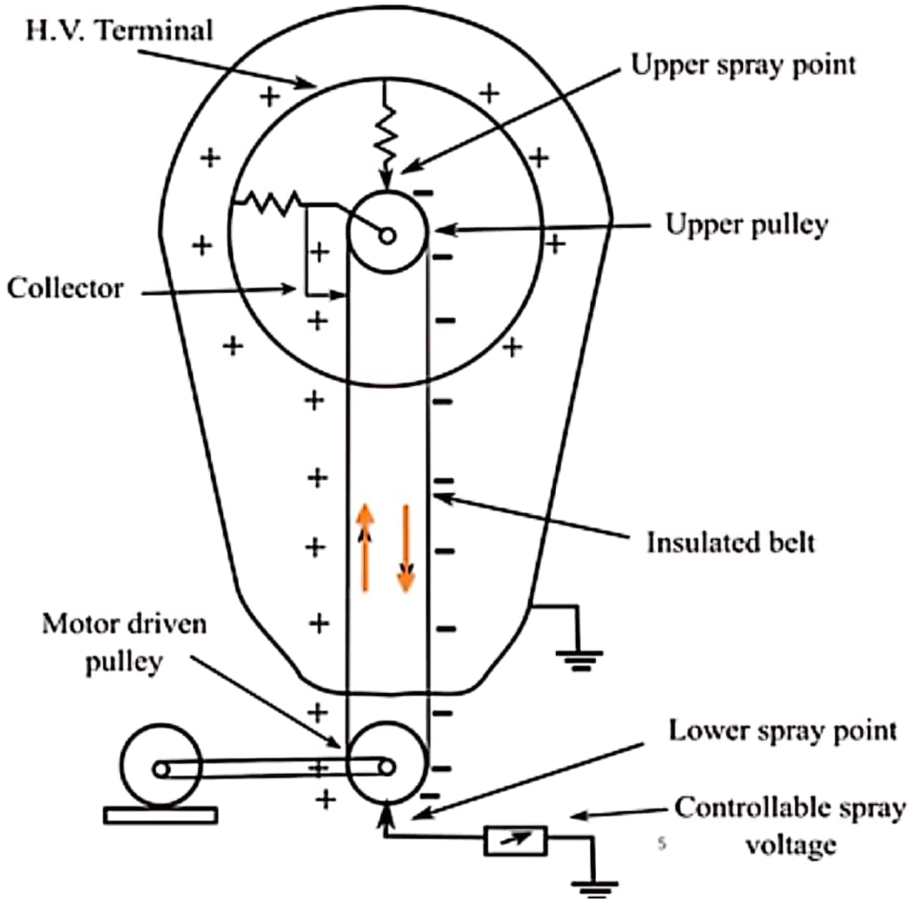
1. To obtain very high d.c. voltages, Cockroft- Walton voltage multiplier is used.
2. The maximum output d.c. voltage obtained using 'n' stages circuit will be less than $2nV_{max}$ due to voltage regulation.
3. It is economical to use high frequency and low value of capacitance is used to obtain minimum ripple voltage.

Principle of electrical energy generation from electrostatic machines:

- ✓ When a conductor cuts magnetic flux, mechanical energy is converted in to electrical energy. This is electromagnetic energy conversion principle.
- ✓ In electrostatic machines, charged body is moved under the influence of electrostatic field and mechanical energy is converted in to electrical energy.
- ✓ An insulated belt with charge on it when moved at velocity 'v', the mechanical power required $P=F.v$ is converted to electrical power $P= V.I$

1.5 Van De Graaff Generator

1. Lower spray point
2. Motor driven pulley
3. Insulated belt
4. HV terminal
5. Collector
6. Insulated upper pulley
7. Upper spray point
8. Earthed enclosure



Circuit operation :

1. An insulating belt is run over pulleys at a speed of 15 to 30 m/sec by means of motor connected to the lower pulley.
2. Near the lower pulley, the belt is electrostatically charged by the charge spray unit in the form of several needles connected to controllable d.c. excitation of 10 to 100 kV.
3. The charge is conveyed to the upper end where it is collected from the belt by the discharge points connected to the inside of an insulated metal electrode through which the belt passes.
4. The entire assembly is enclosed in an earthed metal tank filled with insulating gas of good dielectric strength e.g Nitrogen, Freon, SF_6

Circuit operation :

5. The shape of h.t. electrode should spherical in order to have uniform surface voltage gradient and minimum corona discharges.
6. As h.t. electrode collect charges, it potential rises to high value. To avoid voltage levels that may ionize the electrode surroundings, there is an optimum voltage that may be achieved for given dimensions.
7. When charging current becomes equal to sum of the load current, leakage current and corona loss currents, the voltage reaches equilibrium stage.
8. To minimize distortion of electric field due to belt, it is placed within field grading rings.

Circuit operation :

9. The grading is provided by resistors and additional corona discharge elements.
10. A second point system is excited by a self-inducing arrangement. This enables the down going belt to be charged to the polarity opposite to that of the terminal and thus the rate of charging is doubled.
11. The self inducing arrangement requires insulating the upper pulley and maintaining it at a potential higher than that of the h.t. terminal.

Circuit operation :

12. As the pulley is at a higher potential (positive), the negative charges due to corona discharge at the upper spray points are collected by the belt. This neutralizes any remaining positive charge on the belt and leaves an excess of negative charges.

Advantages:

1. Ripple free output.
2. Flexibility and precision.

Limitation:

1. Low current output
2. Vibration in belt at high speeds.

Summary:

1. Very high d.c. voltages can be obtained by using Electrostatic induction by Van De Graaff circuit.
2. The charges are accumulated at h.t. electrode to produce high potential.
3. The output is ripple free but with low current delivery.